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Economic Structural Analysis

of

Wireless Communications Systems

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ABSTRACT

This paper presents a detailed model and analysis of wireless communications systems. It focuses on the capital and expense elements of the designs and considers differing options with regard to local access. The paper reaches several key conclusion. First, it demonstrates the fact that there are de minimus scale economies in the wireless transport system. Second, it presents an analysis of the effects of the disaggregation of local access and providing switching on a wholesales basis to the wireless carrier. Specifically, the paper argues that Pareto optimal pricing schedules exist and that these require LEC disaggregation and provisioning of services on a marginally equitable pricing basis.

1.0 Introduction

Wireless communications networks have evolved from cellular systems to the current PCS opportunities. Innovations in technologies have led to dramatic increases in efficiencies of both the plant and the operations areas. In addition, the current FCC decisions on opening up the Local Exchange further provide a marginal cost alternative that ensures that the average costs rapidly approach the marginal costs.

The approach taken in this paper is to, first, consider the demand model for the services. This model is essential, not from a revenue perspective, which we leave to the individual operators, but from the perspective of the traffic load on the system. Second, we develop a capital model for the system. This model is based upon one of several existing technologies, namely the current CDMA designs. In this model we consider the use and lack of use of co-location in the LEC. This comparison is essential since it will become the basis of policy analysis and antitrust analysis. We do not include the cost of the set in either the capital or the expense model. This is an incremental unit cost to the user and does not reflect upon the economic analysis of the wireless infrastructure.

Third, we develop an operations model for the business so as to have a fully integrated cost base for microeconomic analysis. This model is based upon actual experience in managing and operating existing cellular systems and this understanding is projected forward into a PCS application.

This model is then applied to a detailed microeconomic analysis of the wireless communications industry. We look at both average and marginal costs, both long run and short run. The analyses performed provide the basis for the development of policy analyses. Lastly, we apply the results from the analyses to the development of suggested policy alternatives. Specifically we reach several conclusions based upon this model that relate to the development of national networks, the economic efficiencies of smaller coalitions, and the antitrust behavior that may be existent in the current structure of the BCCs and the barriers to competitive entry that they may pose to alternative carriers.

It is argued in this paper that there is adequate economic detail available, both in the areas of capital elements and expense elements, and that technology is mature enough to make detailed predictions of the operating efficiencies, that these models should be used as the basis for policy analysis and development. The issue of demand is still a question that is open to the risks associated with the entrepreneurial environment.

It has been argued elsewhere that a new network paradigm has developed and that this paradigm recognizes the separation of switching, transport, interconnect and control.[1] In point of fact, the separation of interconnect from the other three elements was the heart of the Carterfone decision in 1969.[2] In sharp contrast, we can now, and do so in this paper, argue that the other elements are clearly separable. Specifically, we argue that the provision of local communications services is composed of three elements; a retail sales and service element, a wholesale switch company and a wholesale transport

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1. See McGarty, Architectures (1990), wherein the author develops a detailed model for a wide variety of communications systems. Specifically, the author argues that all systems deconstruct into four key elements; switching, interconnect, transport and control.

2. Kahn; the author details Carterfone decision in II 142-144. In this case the FCC clearly, and for the first time recognized the ability to disaggregate the communications system with no harm to the service. Technology had made the interface now separable.

company.[3] The retail entity provides for sales, billing, customer services and new products and services adjunct to the switch. The switch entity sells wholesale switch access on the switch side of the MDF. The wholesale transport entity sells transport of any type on the outside plant side of the MDF. The MDF is the wholesale barrier.[4]

In the wireless world, the wireless company is providing the retail service, the transport entity (as wholesale to itself), and purchases the wholesale switching from the LEC. Unfortunately, the LECs currently sell the wholesale switch access at fully loaded retail prices. We shall show and further argue in this paper that the barriers to entry and scale economies of the wireless busyness are controlled and possibly manipulated by the LEC discriminatory pricing in this tripartite arrangement.[5] To do this we shall develop a detailed model of the economies of a wireless system and then demonstrate the differences in the operations of such systems with and without access in a discriminatory fashion.[6]

2.0 Demand Models

The user demand model is based upon several factors in the market analysis. We shall not discuss pricing or pricing strategy but shall make assumptions relating to the demand curve and the usage related to that demand. Several differences between PCS and the

current PSTN service must first be discussed. These are:

(i) User: The PSTN user is typically the household. A phone number, even in a household is identified with the location and the house and not necessarily with the person. Even such cases as the "Teen Phone" which may be allocated to the teenager are location oriented and not user oriented. That is, the teenager may use other phones at other locations. In contrast the PCS phone is user related, identified with an individual, in most cases, and follows the individual on a real time basis. It is not at all clear as to how cross elastic the PCS service will be with the current wire based service.[7]

(ii) Usage: Usage is the number of minutes of usage per user per month. Current home telephone usage is measured on a household basis and it varies significantly with the demographics of the users. Cellular usage measurements are also highly biased in the upward direction based upon the skewing of the user base to high end users and premium value added to the usage. In contrast, PCS usage is based on an single individual, based upon a portable usage, based on some cross elasticity with the in home wire based phone and may also have some price sensitivity. We shall assume, in this paper, that for analysis purposes, that individual demand is price sensitive, and that a demand curve exists. However, we shall also assume that the price of the service can be reduced to a level that compares with the existing wirebased product and furthermore is usage insensitive. Namely, we shall assume a fixed price unlimited local usage rate. This approach allows for a simpler economic analysis of the problem.

(iii) Uses: The uses are the specific applications and circumstances in which the service is put to use. In the case of standard telephone service the uses are delimited by fixation to the home. In cellular, the uses are dominated, currently to mobile applications, although portable applications are increasing. Current cellular has a portable problem due to coverage and the uses are not yet fully evolved. PCS, however, will have to evolve but it is clear from all of the current trials that the uses are expanding.

(iv) Demand: The demand is represented by the number of users, and the minutes of use per user per day.

There have been many studies on the usage of telephones in the home. The most readable and still current analysis is by Mayer and is in the reference by de Sola Pool. In that detailed analysis the author shows that there typical household, HH, has 120 calls per month, or 4 per day, of an average duration of 4 minutes. Thus the typical home has 500 minutes of usage per month. The typical phone bill for local usage is now about $20 per month per HH. This means that the LEC charges $0.04 per minute for usage, fully loaded. Since the rate base is 75% outside plant and 25% switch, this means that $0.01 per minute is the switch and $0.03 per minute is the

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3. Spulber; pp. 114-115. The author develops the concept of economies of scope for the telecommunications market. In this case if we define S for wholesale switching, T for wholesale transport and R for the retail process, we argue that the total cost function, C(S,T,R) can now with disaggregation be shown to be such that; C(S,T,R) > C(S)+C(T)+C(R), where each of these are supplied by differing parties. Namely, the current LECs exhibit significant diseconomies of scope as well as scale.

4. There are changes in NYNEX, for example, that are trying to reduce the staffing by a factor of 40%. The company currently has about 13 million access lines, 26,000 management, and 52,000 craft. This represents one management per 500 customers and one craft per 250 customers. That represents a total of 6 employees per thousand customers.

5. Spulber, p. 117 defines a natural monopoly as an entity that exhibits significant economies of scale and scope. As we have argued, we shall show that by disaggregating the basic three elements, we shall introduce competitive efficiencies that will clear the market, and dramatically reduce costs.

6. Hovenkamp, p. 116, discusses the Areeda-Turner test for predatory pricing test the price on the marginal cost basis. We shall argue that this is a critical measure, but it must be taken in the context of the overall market minimum if there were competition. The predatory pricing issues of the Robinson- Patman act also apply since internal transfer pricing at prices lower than that provided to competitors for disaggretable elements is prima facie in violation.

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7. McGarty, CMU 1992, has developed a detailed demand model for the PCS business. This has been used as a basis for the summary conclusions made herein.

outside plant. This may actually be less if the Retail element is adequately assigned. [8]

In the analysis in this paper, we shall consider two examples. The first is that an average HH has 3 people (250 million population and 85 million HH) and this means that the average user, as a single person, uses 160 minutes per month per user. Thus we shall create two usage scenarios. The low case is an 80 minute per month, or close to the current cellular usage, and the high case is 250 minutes per month, half the total HH case. We shall also create a peak busy hour analysis in the details of the design that is 4:1 the normal average usage. The system design will use these factors in the development of capital requirements and in operating costs.

The market for wireless service has initially been driven by the upscale user who has been willing to pay a premium price for service access. To date, the revenue per subscriber per month has been close to $80 per month. The current pricing has been on a per minute basis plus a fixed access fee. There are a variety of pricing plans and some companies offer well over a hundred different variants of a pricing plan. In effect, the current user of the service must deal will high and variable prices and plans that are at best difficult to understand. In fact, competition may be based on going after users that are on the competitors pore price plan. This results in churn via price plan arbitrage.

Many of the existing cellular companies are trying to keep usage up and revenue per month per subscriber up. In fact, dilution is a major concern of many of the players. They still position the service as a premium offering.

The question then is, what is the PCS (Personal Communications Service) Market? The answer quite simply is that it is all of those users who are willing to pay as low a price that can be offered for a profitable service. The current cellular market is characterized by a revenue per month per subscriber that is high. The PCS market is at lower rate per month. The estimated elasticity of demand for this market chows that at the $360 per year rate the market penetration is in excess if 8%.

The historical data shows the sliding reduction in the rate per month as the cellular industry has evolved. By 1990, it has gone below $100 per month and the penetration has exceeded 2%. What this says is that the market may have saturated at these high rates. Moreover, what this also says is that cellular penetration will follow the rate of disposable income. Specifically, if greater penetration is desired, then rates must follow a fixed percent of the disposable income. This phenomenon is typical of most commodity services until they are converted into

well accepted needs. At that time the revenue may be increased. This is the phenomenon of CATV. [9]

The current cellular market is the over $75,000 per year household income. The PCS market expands that to the over $50,000 number.

To do enter this market effectively, however, we must ensure that customer perception (CP) is met. It is possible to match CP to system performance (SP). In the classical cellular model the SP was at a level that gave adequate CP. As the customer become more accustomed to the service their level of CP moved to the right for the same level of SP. Thus for a fixed SP, the CP may decrease as the customer stays with the service and demands more.
One of the major problems with current cellular systems is the issue of churn. Churn is the loss of customers to the other company or from the service. In current systems there is a difficulty in getting a customer and no difficulty in loosing them. Some systems have 4% to 5% churn per month. This implies that one may have to work until the 21st or 27th of each month just to keep still.

Thus customer retention is essential. To achieve this it is necessary to develop a two prong strategy. The first part is to ensure low barriers to entry for customers into the service. The second is to have a high barrier to exit.

The barrier to entry is kept low by three efforts;

 o Low set cost

 o Ease of Service Acquisition

 o Low and Predictable Service Cost

The barrier to exit is kept high by four efforts;

 o High service quality

 o High levels of post sale customer attention consistent with a good post sales support. This establishes brand loyalty.

 o Low and predictable service costs. Costs that that pegged to value.

 o High relative performance compared to other telecommunications alternatives and compared to value for other comparable disposable income expenditures. This requires constant reminders to the consumers and education of the consumer.

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8. Mayer, in de Sola Pool, pp. 124-126. The author develops and presents a detailed analysis of usage in the home environment. Although the paper was written in 1977 it still reflects current usage patterns. This is more surprising in that one has seen expectations of increased usage. These have not materialized.

9. McGarty & Clancey, McGarty & Veith, and McGarty & McGarty(1983) provide detailed analyses of the CATV environment and the architectures and pricing mechanisms. Despite the current concern over CATV rates, all of the Franchise bidders knew that their bids based on basic service of $5 per month or about that were made to win the franchise and not to run the business. The business plans reflected an escalation in prices to levels consistent with adequate returns. Thus, the true cause of CATV price escalation was an irrational franchising process that demanded unrealistic and economically unachievable initial rates.

As we have discussed there are two diverging growth strategies. They are best described by the "Hold Revenue" strategy and the "Gain Share" strategy. One holds high Revenue per month per sub but low penetration and the other drives revenue per month per sub down to gain penetration. One is defensive the other offensive.

The "Hold Revenue" strategy assumes that there is a limited market and that there is no more productivity to be gained from the delivery of the service. It is a defensive strategy that tries to keep the revenue high and achieve high short term cash flow. It is typical of the strategies employed by a highly leveraged firm.

The second approach, "Gain Share", is proactive and offensive. It says that growth is obtained through driving the price down and gaining share in a low cost fashion. That is get the share first, don't try to buy it away from some one else. This strategy is the long term strategy, it is driven by a knowledge of the consumer base and a means to continue productivity changes in the infrastructure.[10]

The final issue is that of distribution. Let us assume that we have developed a marketing strategy that is characterized as follows:

(1) Gain share through price reduction, selling a bundled offering at a fixed price.

(2) Establish high exit barriers by providing brand loyalty through quality service.

(3) Develop low entry barriers through ease of acquisition.

The latter is a step towards separating the set from the service. Thus if we look at the market as three segments; niche upscale demanding service, Business segments demanding price and attention, and consumer mass market demanding ease of access, then the latter needs a restructuring of the distribution channel.

The service must be separately positioned from the set. The set should be as available and as universal as the telephone is today. The arguments for why it cannot are reminiscent of the same arguments that AT&T gave 15 years ago when it tried to stop set sales. However, it is clear that AT&T has announced return to the set business and it undoubtedly recognizes the changing distribution in this network.

3.0 Capital Structure

In the analysis of the wireless networks, the first model needed is that of the capital equipment required. The approach that we shall take is one where we first analyze the current cellular systems and then proceed to develop models for PCS. It is important to understand the transition from one to the other for within that transition is a fundamental paradigm shift. That shift takes the systems from a primarily hierarchical design of the old Bell System and their technology to the new distributed designs of distributed computer and communications processing. It is essential that this paradigm shift be recognized and appreciated. It is within this shift that the significant capital restructuring occurs.

There is a second factor that must be recognized as we analyze the economies of the new PCS systems. This is the fact that co-location and services disaggregation of the LECs via Open Network Interfaces will creates new and lower cost access to local telco plant. We have argued elsewhere that the LEC can be viewed as three companies; a retail ales and service company, a wholesale transport company and a wholesale switch company. PCS is replacing the retail function and the wholesale transport function. It therefore requests from the LEC for wholesale switch access at equitable marginal priced levels. This is consistent with the non-discriminatory pricing allowed under Antitrust law. Therefore, this second dimension, allows PCS to compete on a level playing field with the LEC.[11]

These two factors, distributed processing and non-discriminatory LEC co-location access, will dramatically change the capital structure of the wireless business.

3.1 Capital Elements

The current wireless technology as embodied in the cellular communications systems is composed of several key technological elements. Specifically they are the Cell Sites, the MTSO (Mobile Telephone Switching Office), and whatever connections or management systems are in place. The connections between the cell sites and the MTSOs are digital circuits carrying the voice signals.

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10. GAO Report; This report details the impacts of this latter strategy of holding price. Furthermore the report presents details on current prices and penetration. It is clear that the current market is an in restricted duopoly that operates and an effective monopoly in most markets. Tirole demonstrates that within a duopoly with perfect price information, as is the case in the public tariff cellular markets, monopolistic control is possible., pp. 362-365.

11. Hovenkamp, p. 117, details the Areeda-Turner Test about predatory pricing. Simply stated, if the LEC can be segmented as argued, and if the transfer price to the retail entity of the LEC from the Switch entity is less than the average variable cost, then the pricing is predatory to third parties if their price exceeds this level. Simply put, if the transfer price makes the internal segmented entity non-profitable on a stand alone basis, even on a marginal basis, then predatory pricing is evident. This predatory pricing thus creates an unnecessarily high barrier to entry, sustainable over the entire life of the business. Fisher, p. 186, further demonstrates that the "price squeeze" mechanism as demonstrated in the Alcoa Case demonstrated the ability of the company with monopolistic control to squeeze out competitors downstream with predatory pricing.

In this section we shall examine the three network capital elements; the MTSO, the cell sites, and the back haul network.

3.1.1 MTSO and Local Access

The MTSO is a telephone switch that provides a set of functions. The simplest function is that of connecting the wireless user from a cell site to a twisted pair. It, in effect, creates and maintains a virtual circuit from the radio to a twisted pair that goes to the telephone Central Office. This is the dynamic and specialized functionality of the MTSO. All of the other MTSO functions are nothing more than what a Class 5 Central Office Switch performs. It provides dial tone, switches to a trunk, routes the call, does the billing, and supports maintenance functions. In effect, the MTSO is a Class 5 Central Office plus an adjunct function of establishing and maintaining a virtual circuit connection between a twisted pair and a wireless user. The new technology of CDMA takes away some of the MTSO functionality and places it in the cell site. Specifically, in CDMA, the cell site creates the virtual circuit from the portable to a twisted pair.

A Class 5 switch has, from a connectivity point of view, three functions. First, the Class 5 switch takes all of the incoming twisted pairs, there may be tens of thousands, and determines which ones are active. An "off-hook" lets the switch then assign a line. The first function of a Class 5 switch is then to create a physical circuit between a twisted pair and a line access point on the switch. In contrast, the CDMA cell site creates this same connection in the handling of the call. It creates a virtual circuit between a portable and the line side of a switch.

The second function is the assign dial tone and gather the out of band signaling information, namely the DTMF pulses. In CDMA cell sites this is also done at the cell. The cell can provide dial tone and using a SS-7 format it can in an out of band fashion provide signaling data to the switch. Third, the switch connects line units to trunks. This cannot be provided by the CDMA cell. In conclusion, as we shall note latter, a CDMA cell site provides two of the three functions of a Class 5 switch, the switch being needed for only line card to trunk connections, namely a backplane functionality.

The MTSOs are interconnected via the Public Switched Telephone Network (PSTN) of the local Carrier. The local carrier receives a set of digital circuits and their signaling information for interconnection to other non cellular users.

MTSO operations are comparable to a Class 5 central office. Software maintenance and switch control are the typical functions performed, and in addition the MTSO can supply dial tone to the end user. The additional costs of a MTSO are the carrier charges from the MTSO to the PSTN, a Class 5 Central Office. These charges are of an ongoing nature and consist of a fixed plus variable element. Specifically, under the current tariffs, the amount is about $0.11 per minute per voice call. This includes an amortization of many charges from the Local Telephone Company. It is not a marginal cost price of access and switch costs only. In fact, on a per line basis, the cost

for carrier access charges dominate the cost per subscriber. Specifically, charges of $0.70 per minute for cellular include the $0.11 cost. Some systems have to cost as high as $0.24 depending on the LATA interconnect permitted. This should be contrasted to our prior analysis that the LEC has an effective charge of any $0.04 per minute for switch and transport, as well as their retail function. One would question this pricing scheme as anti competitive.

The historical perspective of the MTSO is important. Since the current analog cellular system was first conceived and designed in the late 1960's at Bell Telephone laboratories, the hierarchical network approach of having a Class 5 Central Office per collection of cell sites was integral to the design. In the late 1970's, however, the Bell System realized that it would have to admit competitors and that they would not necessarily be the only service provider. In an attempt to protect co-location access the design was expanded to create a duplicate facility, namely the MTSO, which duplicates almost 90% of the functionality of a Class 5 Office. Thus the MTSO is a artifact of pre-divestiture network protection. It is the lightening block arrester analog of the MDF for local loop access to the cellular world. It is critical to understand this mind set and to deconstruct its rational from th existing technology.

A dramatic change is occurring in 1992. This is the move to co-location and to unbundled marginal cost pricing on an equitable basis. Simply put, this means that anyone may gain just switch access, without an allocation for the plant, and priced at the same level as the Telco, namely marginal pricing, and that a wireless company may co-locate their equipment in the Telco Central Office. In Figure 2.2 we demonstrate that architecture. The Quallcomm QTSO is such an architecture, where the cells are intelligent and an adjunct processor, the QTSO, is placed in the Central Office. This will eliminate the need for a MTSO, shorten the access lines, reduce the access line costs and increase the overall system reliability. It will, in effect put the wireless company in the wireless radio business and keep it out of the telephone switching business.

Therefore, in a CDMA co-located design, there is no need for a MTSO, and furthermore, access to the switch is direct to the switch. This further reduces the access fees as permitted by the recent FCC decisions.

3.1.2 Cell Sites

Cell sites provide for the radio connection between the portable or mobile and a fixed point. That fixed point is the cell and the cell then has identified with it a set of twisted pairs that go back to the MTSO. The current analog cells are not very intelligent and rely upon the MTSO pair/radio virtual adjunct to maintain the logical connection. The cells in the current analog design have limited intelligence and are based again on 1970 designs.

The current cell sites are equipped to handle a bank of frequencies that use two 25MHz frequencies, one for transmit and one for receive. If we assume 1.25 MHz blocks, then we can use splitting of 7:1, which says that there are six adjacent hexagonal cells,

none of which can use the same frequency, thus the 25MHz can be split at best 7 ways. If we further assume that the voice channels are FM and that they use 30KHz per channel, then a single cell can support about 40 channels per 1.25 MHz. In fact on average a cell has about 35 Channels in Analog and may max out at about 57.

The current cell systems are evolving into digital, intelligent and distributed designs. These trends will have significant impact on the operations of a wireless system. In addition there is the impact that technology in terms of digital access will have on the system. Specifically, two digital schemes are developed and are effectively near operational status. These are the TDMA and the CDMA schemes. Each of these has a performance factor that increase the overall performance per AMPS. Specifically:

> o Capacity/Cell: This is the capacity per 1.25 MHz. AMPs has already been described. TDMA is about 3 to 6 times more than AMPs per unit bandwidth. CDMA is 10 to 20 times more effective.

> o Cell Radius: *The effective cell radius depends on the power of the users terminal. There is a significant introduction of 0.6 W devices into the system and these are replacing the 3 W mobile units. The lower power devices are portables and the market is becoming more portable each day. In point of fact, this paper assumes that portable will dominate if not be the only terminal sold in five years. It may be possible to have power boosters for autos, however, the 0.6 W devices will dominate.*

CDMA has a larger cell radius at 0.6 W than does all of the other systems. This is due to the lower E_b/N_o needed for the link. This will have a dramatic effect in achieving the targeted cost per customer number.

Systems may vary in their lifetimes between a capacity driven mode and a coverage driven mode. If we consider the original AMPs system, it was originally drive by capacity and not coverage. The cell radius for 3 W mobile was significant and the number of cells needed were few to cover a large area. As 0.6 W sets became available, the effective cell radius shrunk so that coverage was why cells were built. This cycle will continue. We can characterize these two domains as follows:

> o Capacity Domain: In this case there are enough cell sites out and deployed so that at no time is a unit too far, in terms of distance, from a cell. For high powered units this may be a great distance. For lower power units this may be quite a small distance. However, there are so many users per cell area that the load exceeds the capacity of a cell. To meet the demand, cells must be split and the frequency reused. Thus, the installation of new cells for the reason of hitting a capacity limit is called the Capacity Domain.

> o Coverage Domain: As with the capacity domain, the coverage domain is that

situation when new cells are added because users are too far away from any cell, even though the capacity available from all or any cell is far from being reached.

The current cellular systems were in the Capacity domain two years ago and they were predicting dire results. With the sale of portables this has shifted to the coverage domain. For example, in 1990 it was necessary to have about 75 cells to cover New York in the domain limited by coverage. Each cell had a ten mile radius of coverage, at a minimum, since the mobiles were all at 3 W. Thus a single cell had a coverage area of 300 square miles and having 70 to 75 provided well over 7,000 square miles of coverage. Also, each cell had capacity of 50 channels, totaling 3,000 channels, and with a 2% peak activity ratio, this yields almost 150,000 users. At that point New York was just about capacity limited but with no coverage problem. Enter portables, with 0.6 watts and less than 3 mile coverage. This means a need to increase the cell sites to over 300 to provide coverage. Capacity is no longer the problem, cell division is now a serious problem.

TDMA, as the first digital proposal, was a response to the capacity driver. CDMA, as the second accepted standard, is a response to both the capacity and coverage drivers. To balance the fluctuation between the two domains in a cost effective fashion, it is necessary to have a technological infrastructure that meets the two needs. This infrastructure is CDMA. With CDMA, one can now deploy cells in the following fashion:

> (i) Start with a single cell, which may have the capacity of 400 channels, or at 2% peak activity, 20,000 users.

> (ii) Assume that the area of coverage is 1,000 square miles at the beginning of the system. Assume that the portable are 0.6 W and that the average cell radius is 3 mi. Therefore, a cell has an area of coverage of 30 sq mi and this means that from a coverage perspective we need 30 sites with perfect covering efficiency or 60 sites at 50% covering efficiency. Let us assume the latter.

> (iii) CDMA, unlike the other multiple access schemes, allows the use of re-rads, or cell site extenders. Namely, use the original cell, and rebroadcast the signal on 59 other passive reradiators, that are low cost and conveniently located. Therefore, we need one cell and 59 re-rads.

> (iv) As the traffic grows, if we keep the coverage fixed, all we need to add are the new cells, based solely on traffic constraints.

> (v) In our model in this section, we shall assume that a cell is $500,000 capital plus installation and a re-rad is $50,000 capital plus installation. Therefore, in an analog system, where the fully loaded cost per cell is $1 million, we would need 60 cells or $60 million. In CDMA, however, we need one cell, at $1 million fully loaded,

and 59 cells at $60,000 fully loaded. Therefore CDMA requires $4.6 million as compared to $60 million.

(vi) The CDMA design allows capital to be incrementally added so that the average capital per subscriber is much closer to the marginal capital per subscriber, over the entire range of the business.

3.1.3 Backhaul Capital

The backhaul system is the network that interconnects the cells to the MTSO. In the changing environment of co-locations, this is no longer the same as was in the analog cellular system. Specifically, in the distributed cell with co-location, all that is necessary is access lines from the re-rads to the local Central office where the cell and adjunct may be located. This capital in this case is reduced to access line operating costs.

3.1.4 Network Management

As we indicated, the concept of interconnect and that of cell layout have been evolving over the past several years. This has resulted in a paradigm, typical example, shift. Here we have a layout that follows the hexagonal grid developed in the 1970's for this system. It is based on the philosophy that it is designed from the beginning using the best tool, namely the "Cookbook", and then is never touched. The old network paradigm is characterized by use of maximum power, for a predominantly mobile market, typically is in a capacity limited environment, uses the frequencies to their maximum and is managed in a passive mode. Namely, management of this type of network is through limited alarms and no in situ feedback information.[12]

In extremis, this old paradigm uses design philosophies that select optimal cell sites and result in fights to access the right piece of real estate. The old paradigm takes extensive time to select and install and yields a large value for the cell life cycle cost factor.

The new paradigm is driven by the desire to be flexible and to drive the cell allocation and utilization in a fashion that maximizes the Net Present Value of the business. It clearly is a system approach that does not follow the book.

The new system requires a new and innovative approach to network design and management. In most of the current cellular systems the management techniques are very antiquated. They have delimited capabilities to handle the complex propagation properties, do not measure the field as viewed by the users and do not

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12. McGarty & Ball discuss the concept of Network management and discuss the significant capabilities now available in a fully distributed fashion. McGarty, Architectures 1990, details the discussion of the control element and how current distributed systems allow this to occur. McGarty, TPRC 1992, demonstrates the evolutionary characteristics of this system.

take into account the time varying nature of the propagation. Thus the performance of many of the current cellular systems are very poor to impossible. As characterized by the CEO of a Cellular System, the have "Snap, Crackle, and Drop". Unfortunately, this CEO never corrected the problem and had less than half the market share of his competitor. To operate a system one must understand the service given to the customer. The Network Management System must achieve this goal.

The new paradigm for system operation with such a network management system is characterized in three key ways;

(1) Flexibility of design and layout. Using sophisticated design tools, sub optimal sites are chosen based upon a life cycle cost methodology.

(2) Minimization of Average and Marginal Capital per user. The costs of leases, service, care and upkeep are critical. The system uses a dynamic network management and control system that dynamically measures the field strength of the system via sensors in the field and from this generates a feedback to the cell sites to optimize performance. This allows for a fully automated optimization of the cell operation in a holistic fashion. It focuses on reducing the operations side of the life cycle costs. It does this by allowing for maintenance and repair dispatching on a more orderly basis, allows for the management and control of spares and inventory, and allows for the changes in cells when new ones are added or in the event of environmental propagation changes.

(3) User measurement with the intent to maximize customer perception. Having the in situ measurement devices, not only can we adjust the cells to meet system performance factors, but we can also adapt and manage the system to meet the necessary customer perception factors.

The control concept provides the use of the sensor data as the input to a propagation and control algorithm that optimally adjusts the cell sites. Use of this technology will dramatically reduce costs.

In this section we have focused several key technical factors that will result in cost reduction. These are;

o Co-Location: Eliminates MTSO and reduces the per line access charge.

o Network Management: Reduces the up-front planning costs and reduces the ongoing maintenance and repair costs. Improves performance and customer reception.

o CDMA Digital: Increases the number of cells and thus reduces depreciation. Makes for simpler planning.

Implementing these three elements will drive down both the operating and depreciation costs.

3.2 Capital Model Analysis

Having developed the details of the model environment we can now develop the details of the capital model. The model requires the following capital elements:

(i) Cell Sites: These are the processing nodes and are not to be confused with the re-radiation sites, microcells, that have been discussed elsewhere.

(ii) ReRads: The rerads are the cell site extenders. They are in a CDMA environment merely RF extenders to achieve coverage and basically make a cell cover an area that makes the effective cell loading a maximum. If we recall that the desire is to match capacity and coverage. namely, we need coverage and that the capacity is an independent issue. With CDMA we can separate the two issues, using the cell site for the establishment of the virtual circuit and re-rad control and the adjunct for switch interface.

(iii) CoLocated Adjunct: The co-located adjunct must be associated with a cell or cell cluster. As we have already demonstrated, in the CDM environment, we expand cells as capacity is increased. Adjuncts can handle several cell sites and a cell can handle many re-rads. Thus, for a typically large system, the cell may handle 400 channels, the adjunct may handle 4,000. Thus we have one adjunct per ten cells.

The capital model is then developed in the following manner. For each capital element, i, we have a capital added in year k denoted as:

$$C_i(k)$$

We then define three parameters; the revenue driver, RD_i, for the ith element, the performance factor, PF_i, and the unit capital, UC_i. Thus, we can show that;

$$C_i(k) = RD_i(k) \; PF_i(k) \; UC_i(k)$$

For example, if the coverage is 1,000 miles, then RD for the re-rads is this coverage area. The PF for this using is the coverage area per re-rad (effective) and the unit capital is the fully loaded capital of $60,000, as we assumed.

Similarly, if we look at the cells, the RD is the product of the number of customers times the erlang load per peak busy hour per customer. The PF is the erlang capacity for the cell, and then the UC is the capital per cell.

We now consider two cases. The first case is that allowing co-location and the second demands a separate MTSO and higher access fees. We further consider the analysis oft the business based upon two usage factors; 80 minutes per month per user and 250 minutes per month per user.

Case 1: (Co-Location)

The model shows the capital per subscriber, at the end of the year, for three categories; cell sites, rerads, and miscellaneous. Three observations are made on the first set of curves. First, the cell capital is generally independent of the number of users and thus does not exhibit scale. This is a unique characteristic of CDMA and is not at all the same in any other multiple access schemes. Second, the capital for the rerads per sub has scale, as expected. In this system we have used the rerads, a low capital item, for the up front coverage problem. This shows that the capital per sub with the rerads is almost $200 er sub at the low end and then decreases dramatically.

Third, we have continued to add about $40 of miscellaneous capital per sub for items such as computers, network management and other items.

When we look at the lower usage rate, of 80 minute as compared to 250, we see the only difference is the reduction in cell capital per sub. All other elements are the same. There is in the low end case a small scale effect of cells at the 25,000 user level but above that we add cells in such small increments that scale in long run costs is de minimus.

Case 2: (No Co-Location)

In the case with no co-location, the MTSO or switch is needed. We show this case with the 80 and 250 minute usage in Figure 3.2 a and b.We can see from both of these figures that there is little scale and that the switch shows scale more so in the lower usage set than at the higher. Also at the lower set we see the effects of adding new switches as we grow the system. The no co-location case has an added 25 to 35% increase in capital per sub.
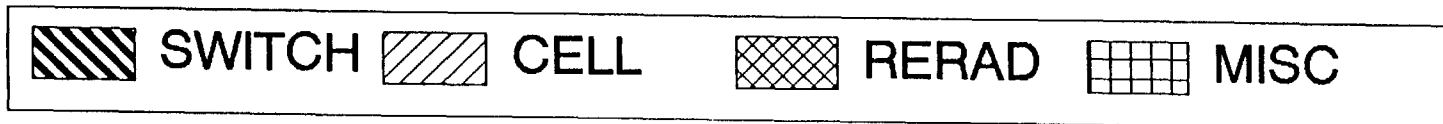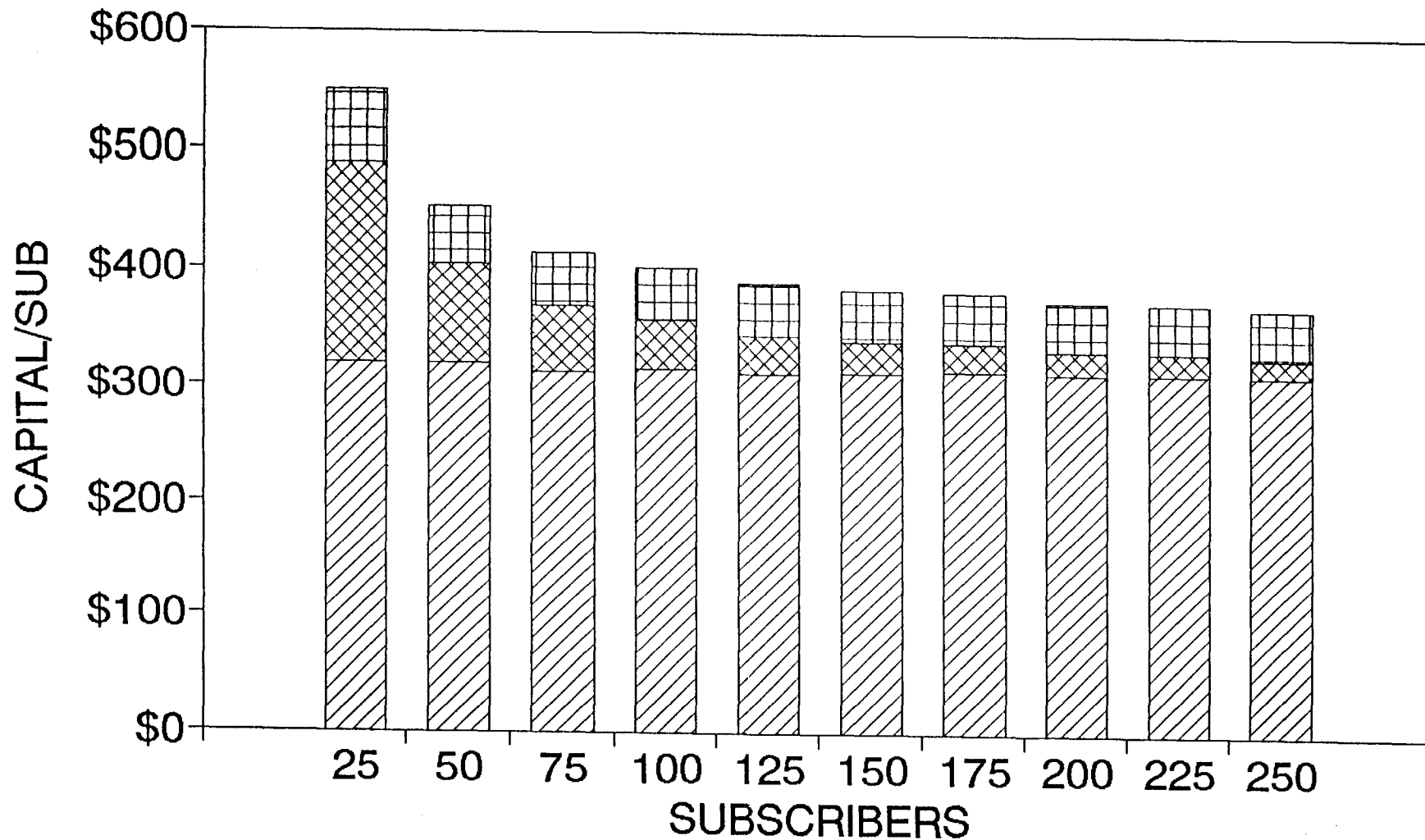
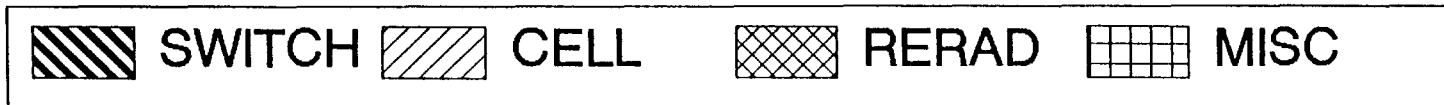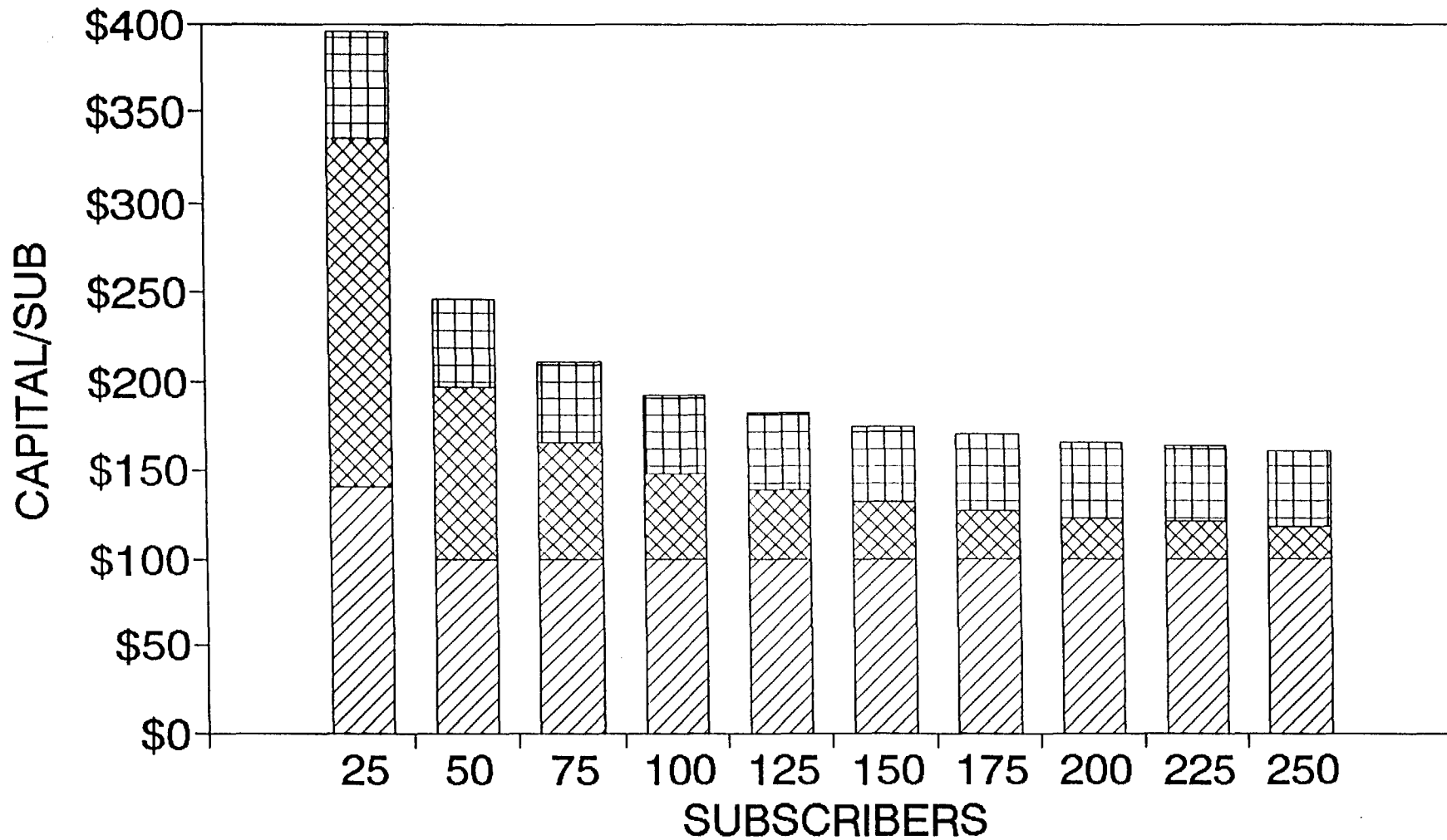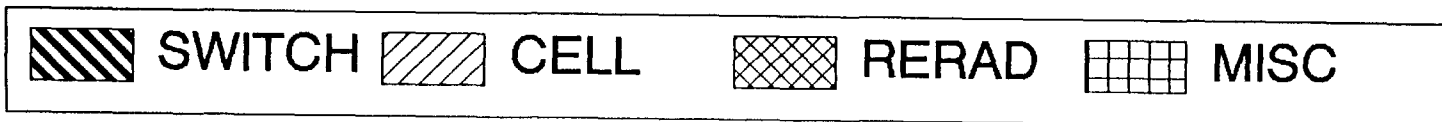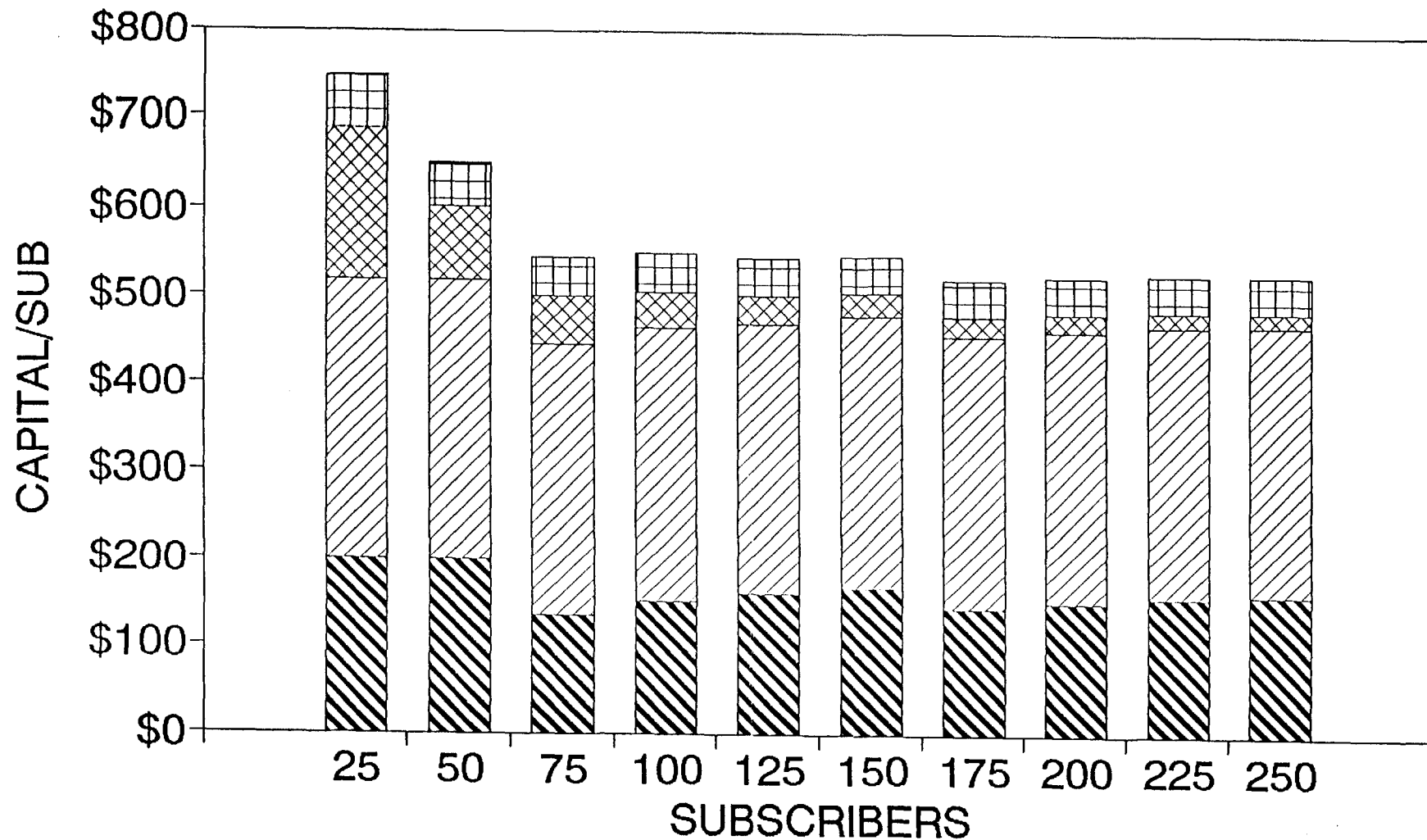Carnegie Mellon Univ., Advanced Telecom Institute, Feb., 1993

Figure 3.1 Capital Per Subscriber (Co-Location)   (b) 80 minutes per user per month
(a) 250 minutes per user per month

CAPITAL/SUB
COLOCATED

CAPITAL/SUB (y-axis): $0, $100, $200, $300, $400, $500, $600

SUBSCRIBERS (x-axis): 25, 50, 75, 100, 125, 150, 175, 200, 225, 250

Legend: SWITCH, CELL, RERAD, MISC

CAPITAL/SUB
COLOCATED

CAPITAL/SUB (y-axis): $0, $50, $100, $150, $200, $250, $300, $350, $400

SUBSCRIBERS (x-axis): 25, 50, 75, 100, 125, 150, 175, 200, 225, 250

Legend: SWITCH, CELL, RERAD, MISC

Figure 3.2 Capital per Subscriber (No Co-Location)   (b) 80 minutes per user per month
(a) 250 minutes per user per month

CAPITAL/SUB
NOT COLOCATED
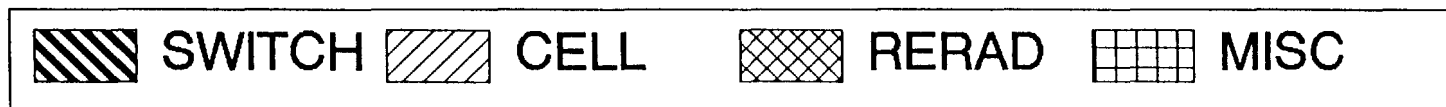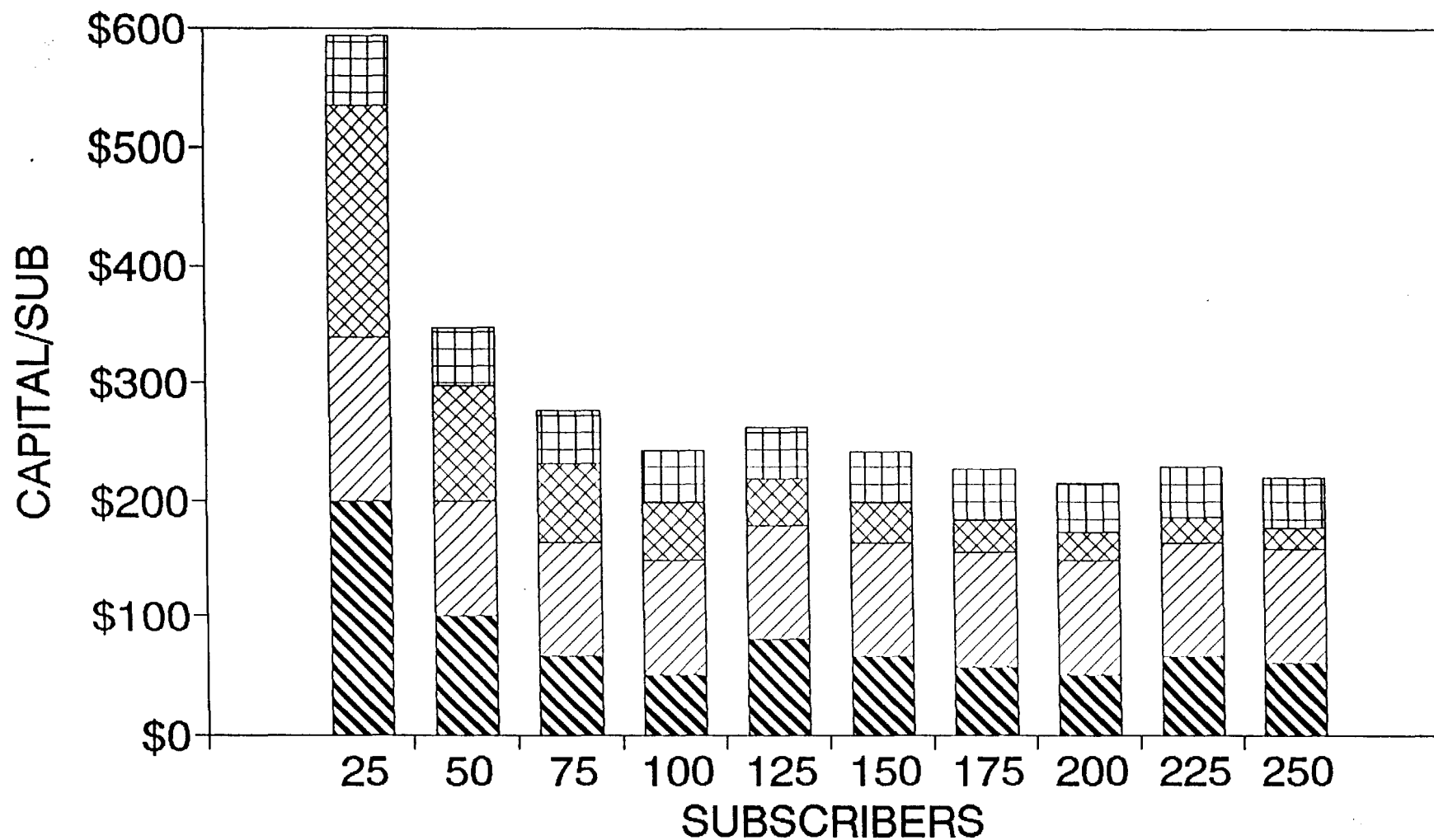

CAPITAL/SUB (y-axis): $0, $100, $200, $300, $400, $500, $600, $700, $800

SUBSCRIBERS (x-axis): 25, 50, 75, 100, 125, 150, 175, 200, 225, 250

Legend: SWITCH, CELL, RERAD, MISC

CAPITAL/SUB
NOT COLOCATED

CAPITAL/SUB (y-axis): $0, $100, $200, $300, $400, $500, $600

SUBSCRIBERS (x-axis): 25, 50, 75, 100, 125, 150, 175, 200, 225, 250

Legend: SWITCH, CELL, RERAD, MISC

4.0 Expense Structure

In this section we develop a business model for the wireless business. We incorporate the operations and marketing aspects that have been developed in the previous two sections. The prior concepts have been placed within the overall constructs developed in McGarty [1989] for many business development models. The approach is to generate the revenue driver-productivity factor-unit cost model of McGarty (eg RD-PF-UC). We defer specific considerations of performance to the next section. The objective of this section is to establish the overall framework.[13]

The overall construct uses a market demand module that drives revenue and the revenue in turn drive expenses, capital and any other elements of the business.[14]

Specifically, for any unit expense element, the unit expense is the product of three elements; the revenue driver, the productivity factor and the unit cost. The revenue driver is derived from the revenue model which in turn is driven by the demand module. The revenue driver tells how the business is exogenous developed and evolved. The productivity factor is an immediate reflection of the management philosophy and strategy. Namely, low overhead ratios or low administrative ratios indicate efficient management.

The overall business can be divided into four interlocking elements. They are the customers, who generate the revenue, the sales function which captures the customers, the operations elements that provide the service and the support functions that underlay the sales and operations infrastructure. This general view will be further detailed when we develop the model of a wireless service.

4.1 Business Construct

The wireless business can be divided into the three areas that we defined above; sales, operations and support. There is another way to view this model wherein we place sales in the Retail side of the business and operations in the Wholesale. This division will be used because it reflects the way most cellular companies currently function. This structure begs the question of how the distribution channel works. Namely, if there is a single internal sales channel then there is no retail or wholesale division, since there are no other sellers of the service. On the other hand if there are other sellers

it is necessary to have a wholesale side sell to the resellers and a retail side be one of the sellers. We shall continue to use this division in latter analyses, interchangeably with the original construct.

The sales organization is composed of the following functions:

o **Sales Channels:**

    o Direct Sales: This is the company's own sales force. In the model that we have developed we have assumed that the sales force is limited to niche markets and that the primary sales approach is through advertising, direct mail, and supported by a telemarketing service.

    o Telemarketing: This is a company owned channel support facility that responds to customers requests generated via advertising channels. This is both an inbound and outbound telemarketing service. On in-bound, we assume that leads are generated by advertising, print, radio, and video, and the telemarketing in-bound representatives handle them. The outbound generation is done on targeted markets.

o **Promotion:** This is primarily the advertising function. As a consumer type product, promotion is essential. The amount and type depends on the targeting of the markets addressed. It is expected that promotion is a key element to this business since it is primarily consumer oriented and a direct sales approach that was used in cellular for a niche market will not work in this case. Several market research studies have verified this fact as has the success of the systems in Hong Kong.

o **Customer Service:** This is basically for inbound calls; calls relating to service problems, disconnects and billing problems. If the network quality is good and the billing is accurate then this is a limited level of effort. In some existing systems, 50% of the calls are due to billing errors and 45% due to service problems. Thus a 95% reduction of typical systems is achievable if the operations are done properly. In the model we make detailed assumptions concerning these operations.

o **Collection and Billing:** This is bill preparation and collections on unpaid bills. It is an overall revenue assurance function for the company on the retail side.

The operations organization is composed of the following elements;

o **Engineering:** Responsible for the design and planning of the system. Generally this function has a fixed base and grows slightly with the system growth.

o **O&M:** Responsible for network management and repair. The costs associated with this system operating costs of the cell and the

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13. McGarty, Business Plans. The reference details the approach contained in this paper. The approach has been specifically developed for the telecommunications industries. The author has also used his experience in operating cellular systems to augment the model presented in this paper.

14. Reference to Porter's two works can be made here. The analysis of the business along lines of process and function rather that organizational structure is based upon the Porter model of value chain. This model or construct allows for the determination of key strategic competitive factors and allows for the comparison of multiple competitors or alternatives.

re-rads, as well as the carriers charges for the PSTN. For a cell there are specific life cycle factors that control its overall costs are:

o Cell Site Location and Planning

o Cell Construction

o Cell Installation

o Cell Operations

o Cell Maintenance

o Cell Repairs

The first four items are part of the initial capitalization and may take anywhere from six months to two years, depending on how quickly access is allowed to the site. The last three elements are ongoing. In some systems, the sum of all these costs for the full life of a cell, seven to ten years, may be two to three times the cell installation capital. Thus cell site life cycle costs are a critical factor to manage in a system.

All other functions; administrative, support and overhead, are lumped under the category of administrative. We have made certain assumptions about the administrative level, namely managers, and the overhead level, namely rents, benefits, and other elements of indirect costs that are competitive to normal business. We have not used Bell System numbers that are typically a factor of two higher that all industry norms.

4.2 Detailed Model

The detailed model of the business is built around the element of revenue, driving expenses, cost of goods and capital. We can develop the overall concept by considering a single element, namely customer service. We can depict the customer service function and show that the expense of this element are derived from the product of three factors. Consider the following example:

o Revenue Driver: (RD) This is the total number of customers who call because of problems of any sort. The more customers, the more calls.

o Productivity Factor: (PF) This is the product of two elements; the calls per day per customer and the holding time per call. Here is where business strategy comes in. If the company operates with no problems, as per the Maytag Service Man, then the arrival rate of problems is zero. The net expense is zero. In effect, ideal customer service is no customer service; namely there are no customer problems. Calls are due to service problems, billing problems and disconnects. If the company can manage those through quality service provision then this cost is reduced. The second element is the holding time per call. With proper systems this should be kept at a

minimum. If the customer is made satisfied, then customer service may also be positioned to sell services to a happy customer. The PF is the most strategically important factor in the business.

o Unit Costs: (UC) the unit costs are the salaries paid to the employees. Thus, one strategy is the pay low salaries. This may however increase the calls because of unhappy customers. It is important to look at the overall product as a concern. Therefor, it may be advisable to pay good wages to attract good CS staff and in turn generate happy customers and thus reduce the call rate. This is a multiplicative effect.

We have developed this model in detail for the entire business. As with the capital analysis we have analyzed the model for case of co-location and on co-location, and at low and high usage rates. The results of this analysis are presented as follows.

Case 1: (Co-Location)

The analysis of the two usage cases are shown in Figure 4.1. We have shown all sales and service costs, operations costs, carrier costs and depreciation. We have allocated administrative and overhead to the department costs but not the carrier costs. The results for both the low usage and high usage case are obvious. We have assumed an access fee of $0.04 per minute per user, four times the internal LEC transfer price, yet one third the current LEC tariff. The results are clear:

(i) Sales per subscriber are high at the beginning since the sales are for the small base of new subs which are in effect all the subs. Latter the sales per total sub are lower, even though the sales per new sub are high.

(ii) Operations also shows scale. We have expensed the manpower for construction and have not depreciated it. This shows scale.

(iii) The cost per sub of the carrier charges is the only fixed element. It is nothing more than the minutes per sub times the rate. This will be the same for Case 2. Note that it represents almost 40% of the total costs in the large user base.

(iv) Depreciation is a nominal factor.

Case 2: (No Co-Location)

We see in Figure 4.2 the results for the non co-located case. The two cases, high and low usage are shown. The immediate difference is the percentage of the total costs due to the carrier. There high case shows almost 80% of the cost are going to the LEC. All other costs are comparable. Thus, at $0.11 per minute, the current rate in some markets, the user of this service is clearly underwriting the LEC, and at discriminatory prices. The wireless company clearly demonstrates improved efficiencies in transport and

retail, and is being discriminated against in the
wholesale switch.

Figure 4.1 Expense per Subscriber (Co-Location)   (b) 80 minutes per user per month
(a) 250 minutes per user per month

EXPENSE/SUB
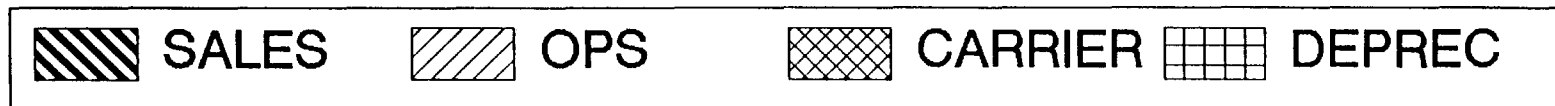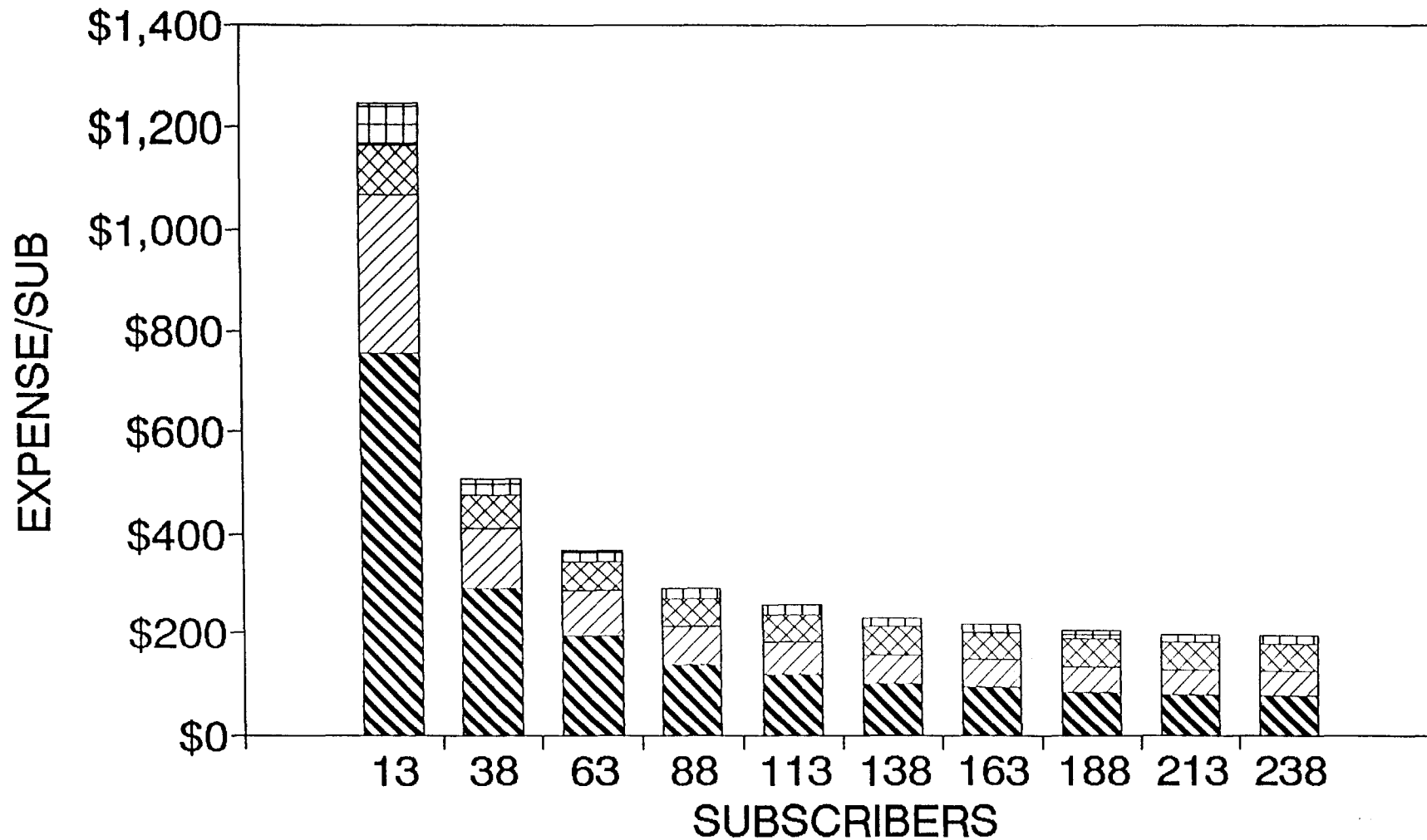## COLOCATED
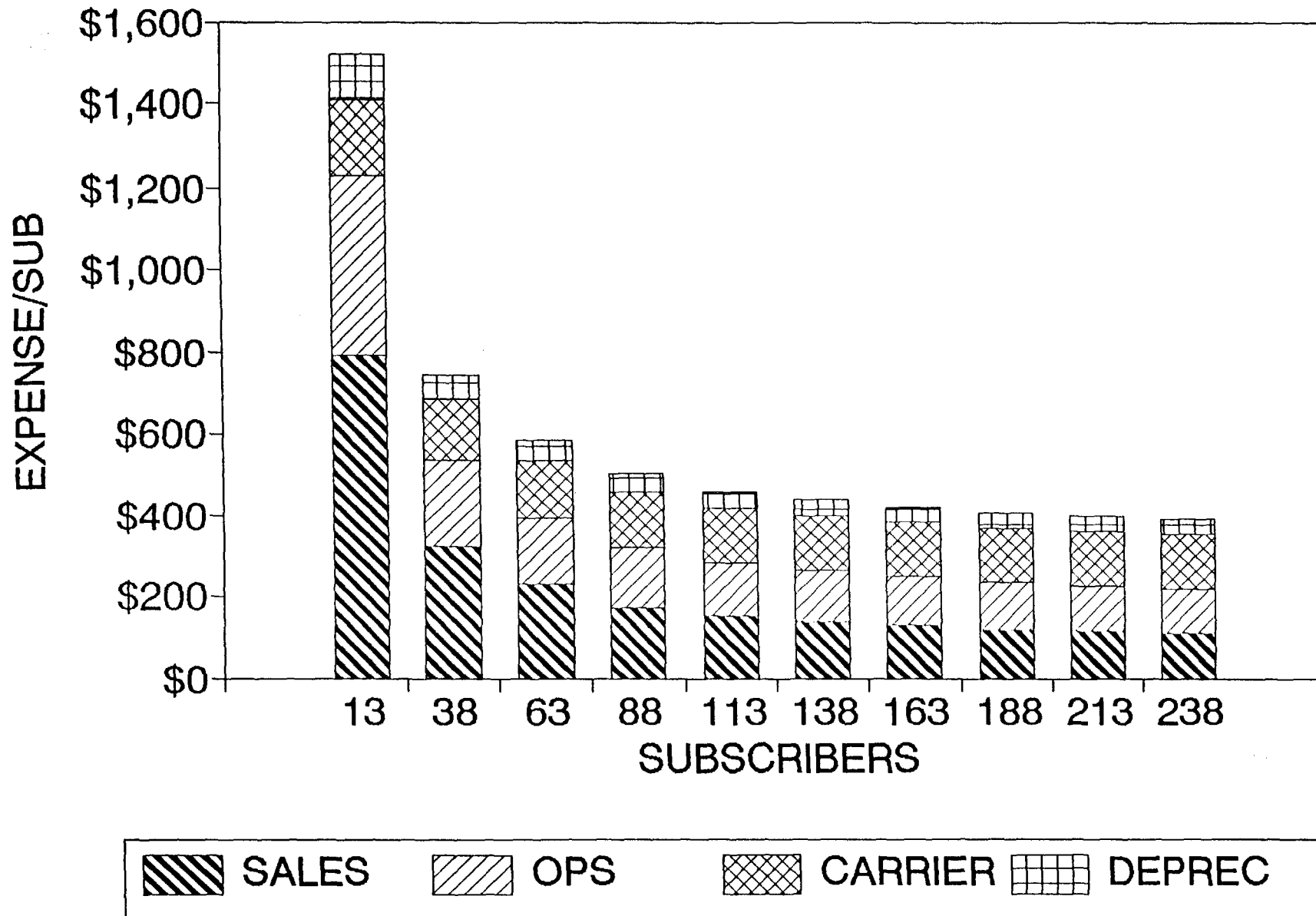
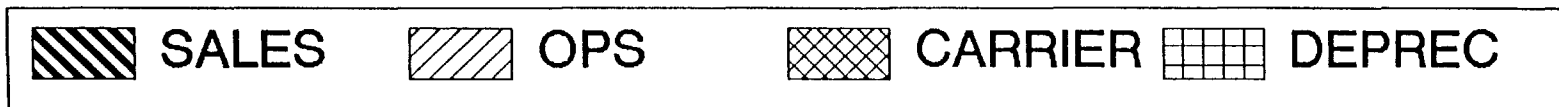Stacked bar chart showing EXPENSE/SUB versus SUBSCRIBERS. Y-axis ranges from $0 to $1,600 in $200 increments. X-axis categories: 13, 38, 63, 88, 113, 138, 163, 188, 213, 238.

Legend: SALES, OPS, CARRIER, DEPREC

EXPENSE/SUB
COLOCATED

Figure 4.2 Expense per Subscriber (NO Co-Location)   (b) 80 minutes per user per month
(a) 250 minutes per user per month

EXPENSE/SUB
NOT COLOCATED

EXPENSE/SUB

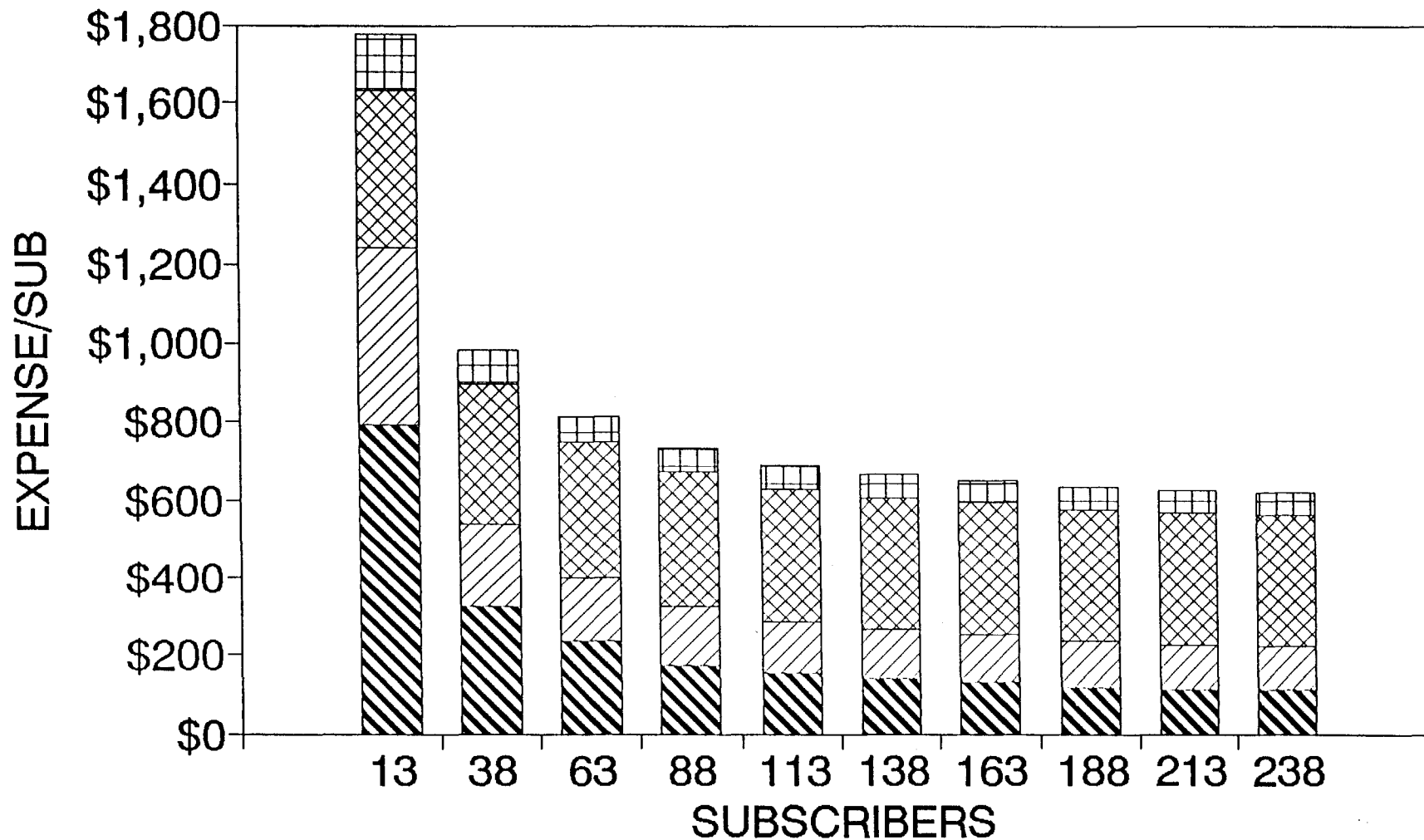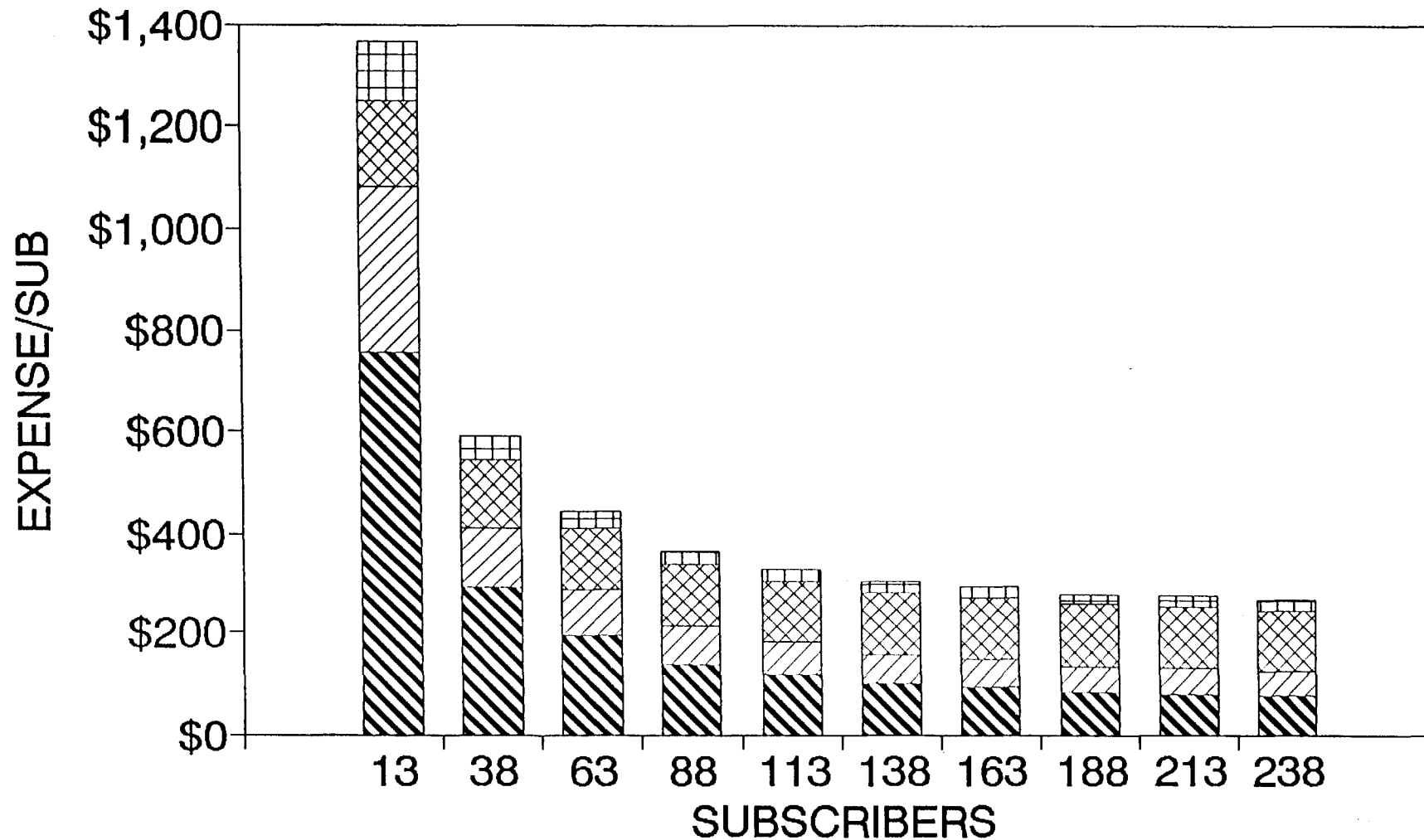SUBSCRIBERS

SALES   OPS   CARRIER   DEPREC

EXPENSE/SUB
NOT COLOCATED

Bar chart showing EXPENSE/SUB (y-axis, $0 to $1,400) versus SUBSCRIBERS (x-axis: 13, 38, 63, 88, 113, 138, 163, 188, 213, 238). Legend: SALES, OPS, CARRIER, DEPREC.

5.0 Scale Economy Analysis

Having developed the models for the capital and the expenses for this business, we shall now consider the costs on a per subscriber basis for the business. In particular we are interested in evaluating the average and marginal costs, both in the short run and the long run.

There are several issues that must be considered before analyzing the model. These issues relate to the allocation and timing

> (i) Timing: How rapidly we introduce new customers. Namely, the first customers bear the brunt of the sales costs, averaged on all customers.

> (ii) Allocation: The way we allocate costs. We have used a depreciation schedule that is seven years. This is a rapid schedule that is a great deal quicker than the 40 year schedule of the Class 5 switches of the LEC. It is however a reasonable one in terms of the change of the technology.

> (iii) Lifetimes: This is an issue of real lifetimes as compared to depreciation. We have tried to make them the same.

> (iv) Base: The base is the averaging base. We have use both the end of year number and the average number. In the scale case, we have used the average number of customers in the year, not the end of year numbers.

> (v) Rates of Penetration: The scale numbers can be impacted upon by the rates of penetration. Knowing that depreciation has a schedule of a fixed number of years, we would like to get the subscribers on as quickly as possible.

> (vi) Demand Factors: All of the analysis will ultimately depend on demand. Demand is price and pricing sensitive. We have deliberately neglected to discuss this in this paper.

Based upon the models for the wireless business and assuming that we have a seven year capital life, allocating the start up costs over the same time base as the capital life, we have obtained the average and marginal costs per customer as a function of the number of customers. We define the average and marginal costs as:[15]

$$C_A(n) = C_T(n)/n$$

$$C_M(n) = dC_T(n)/dn$$

and we have performed this analysis for two cases. The first case is the co-located, non MTSO case where the LEC provides access on a marginally equitable pricing basis. The second case is that of a non-colocated case requiring a MTSO and the continuation of LEC access charges that are in disequilibrium with internal LEC transfer prices.[16]

We furthermore develop a measure of the cost elasticity, E_C, that is defined as:

$$E_C = C_M(n)/C_A(n)$$

We use standard long run cost measures, assuming that with the shortness of depreciation and the modularity of the capital plant, the long run and short run cost will be identical. We also let the total costs be:

$$C_T(n) = Exp(n) + Dep(n)$$

The following two cases are for the standard analyses that we have been developing in this paper.

Case 1: (Co-Location)

This case assumes that a co-location is permitted. Figure 5.1 presents the average, marginal costs and the cost elasticity. The marginal costs are abut $350 for this high usage case. It should be stated that about $250 can be driven out of this with a lower usage or lower access fee. This is a critical factor from a policy perspective.

Note, also, that the average costs drop rapidly, and that if we are to look at the elasticity, and recognize that whenever the elasticity is close to 70% or better, we have de minimus scale. This occurs at about 85,000 subscribers. Therefore, scale is limited in this analysis.[17]

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15. See Pindyck and Rubinfeld. Also see Henderson and Quandt. It should be noted that we have not clearly selected long run or short run costs. The standard analysis of both sets of authors assume the ability to separate plant from production. In this case the technology allows the marginal expansion without significant initial capital investment.

16. The papers by Oniki and Stevenson and by Lehman and Wiseman discuss the economies of current private networks. They discuss the fixed and variable cost elements of such networks and argue the need and efficacy of monopolistic structures at the detriment of private networks. The arguments are based on the non-decomposability of the LEC or equivalent. In contrast, we have demonstrated that the LRMC and SRMC are comparable, see Henderson and Quandt, pp. 83-92. Specifically, using the Henderson and Quandt approach, the firms costs are $C=F_1(q,k)+F_2(k)$, where q is the quantity produced and k is the plant size parameter. We have shown that the k parameter is small compared to that of the LEC hierarchical network. This is a direct result of the distributed technology available.

17. Kahn, pp. II 127-128, discusses the inherent scale economies in the old Bell System. This discussion was framed prior to divestiture and the argument made in this simple case has clearly shown that this is no longer true. What we have shown here is the divestiture of the LEC, an a natural next step to the 1982 Consent Decree.